LCA Methodology

Application Dependency of LCA Methodology: Key Variables and Their Mode of Influencing the Method

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Abstract

The reason to perform an LCA is essentially to use it in support of a decision. A decision gives rise to a change somewhere in society compared to a scenario in which this decision was not taken. The key requirement for the LCA in any application is therefore, that it shall reflect the environmental change caused by the decision. It is found, that the need to differentiate LCA methodology for the use in different applications is born by a few key characteristics of the decision to be supported.

The first key characteristic is the environmental consequence of the decision, i.e. the nature and extent of the environmental change caused by the decision. When modelling the environmental change, its extent in time and space will differ between decision types, thus giving rise to different requirements, primarily for the scoping and inventory phases of the LCA. Furthermore, some decisions will imply trade-offs between different impact categories, while others will not, thus causing different requirements for the impact assessment. The second key characteristic is the social and economic consequence of the decision, the magnitude of which will influence the need for certainty, transparency and documentation. The third characteristic is the context in which the decision is taken, including the decision maker and interested parties, implicitly influencing the impact assessment and weighting.

Keywords: Life Cycle Assessment; LCA methodology; LCA applications; LCA application dependency; decision support; decision context; environmental consequence; trade-offs; time scale; site dependency; trend analysis; projection; matrix LCA; screening LCA; cut-off criteria; transparency; uncertainty assessment

1 Introduction

Life Cycle Assessment (LCA) is used as support of decisions in a wide range of applications at the society, company and consumer level. The LCA methods used in these applications are still far from being uniform, and the discussion on LCA methodology is ongoing. In the effort of striving for better methods and of harmonizing methods, there is, however, growing awareness that different applications may have different requirements for the method, and that full harmonization on a very detailed level should not be sought.

A number of LCA researchers have grouped LCAs in different application categories (LINDFORS et al., 1995), (WENZEL et al., 1997) and within the International Organization for Standardisation (ISO) a categorization is given in the recent ISO 14040 standard. These categorizations are based on contextual and pragmatic groupings of applications such as marketing, product development, ecolabeling, etc., and common for them is, that they have quite many overlaps between categories and that they do not provide an explanation as to why and how the different application categories may give rise to different requirements for the method. A number of researchers have started clarifying these questions (WEIDEMA, 1993; WENZEL, 1994a, b; BAUMANN, 1995; FÖRSTER, 1996), and the findings of these authors have contributed to the findings presented in this article. The main substrate for the article is, however, own practical LCA work and reviews including research studies, consultancy work and university censorship.

The aim of the article is to contribute to the clarification of application dependency of LCA methodology and to facilitate an understanding of the key variables, that give rise to differences in methodology, and of how they exert their influence. In WEIDEMA (1998), a review of the present status is made, including the above authors and the article in hand.

2 Basic LCA Levels

Practical experience shows that three levels of LCAs tend to be found in the process of extending, quantifying and detailing the information to meet the need in a given decision support. The levels are here called:

1) a matrix LCA, including qualitative or semiquantitative information and calculations by hand or pocket calculator,

2) a screening LCA, including quantitative information based on readily available data in databases etc. and calculations typically on a PC-tool, but including no new data inventory, and

3) a full LCA, including quantitative information and new data inventory and calculations typically on a PC-tool.

Figure 1 illustrates these levels.

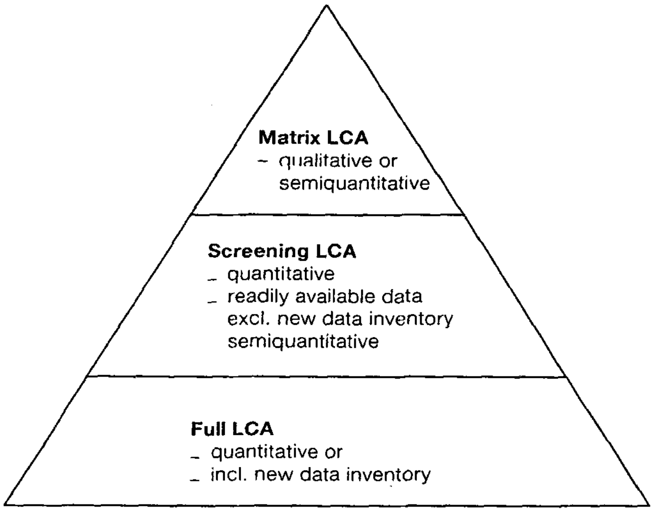

Fig. 1: Basic levels of LCA when extending the work to meet the needs within the application

The borders between these three levels represent key questions in the quantifying and detailing of the LCA. The first crucial point is whether to allow the decision to be based on qualitative information or whether the LCA must be quantitative on all essential impact categories. The next crucial point is whether data are readily available in-house or whether – and to what extent – new data collection is necessary. Crossing a border will each time represent a heavy increase of work as illustrated in Figure 2.

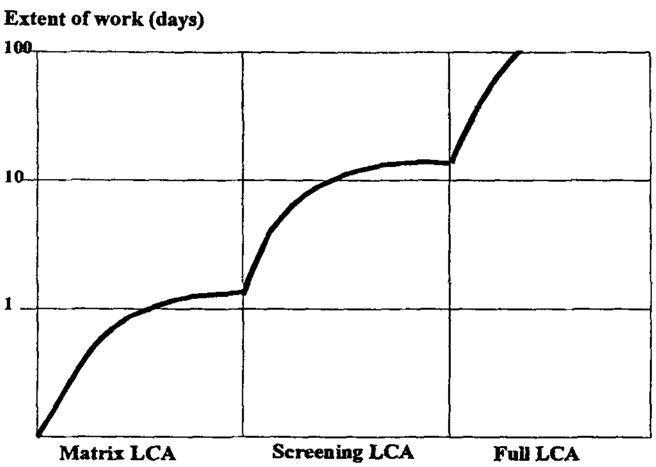

Fig. 2: Extent of work required at different LCA levels. Rough average time estimates

The establishment of good databases and the enabling of databases to communicate with each other will tend to reduce the extent of the work required, i.e. to pull the LCA from left to right by reducing the need for new data inventory. The need to extent the LCA work, by quantifying, detailing and improving its information base, is governed by the key variables identified in this article. The three basic levels of LCA represent a graduate increase in the quality and quantity of the information to support the decision. They are presented here in order to facilitate the understanding of the way in which the LCA is influenced by the key variables.

3 Key Issues in Application Dependency

"The proof of the pudding lies in the eating" says a proverb. The identity and validity of a thing is born by its being used for its purpose – a pudding is not a pudding unless it is eaten. And, if one dares the extrapolation, an LCA is not an LCA if it is not used to support a decision.

This point is essential to understanding the requirements for the LCA method. An LCA that does not support a decision does not have an influence, it does not give rise to a change. Such an LCA is not interesting, and nobody cares what kind of method was used to perform it. When the LCA is suddenly used, however, and someone takes a decision on the basis of the information from that LCA, a change will occur somewhere in the world compared to a scenario in which that decision was not taken. In that case, the LCA should reflect the change that actually occurs, i.e. the actual change should be the one modelled during scoping and inventory, for else the premisses for the decision were false. The decision to be supported, therefore, is the basis of the LCA method in any application, and the actual consequence of the decision should be well foreseen and well reflected by the system models within the LCA. The basic hypothesis of this paper is that the essential variables, that cause a need for application dependent differentiations in LCA methodology, all derive from differences in the consequences of the decision and in the context in which the decision is taken. The key variables causing a need for method differentiation are divided into three groups:

The decision consequence
1) The environmental consequence of the decision
2) The economic or social consequence of the decision

The decision context
3) The context in which the decision is taken, the position of the decision maker, the interests and position of other parties

These variables have different ways of influencing the LCA methodology and they exert their influence in different components of the method.

4 The Environmental Consequence of the Decision

The overall requirement for LCAs in all applications is, thus, that the system models behind the inventory reflect the environmental consequences of the decision as well as possible, i.e. reflect the actual difference in inputs and outputs from

the industrial systems affected when choosing one alternative over the other.

In the effort of achieving this, however, the work should in practice not be overdone. The work with the LCA to meet the needs and requirements of the decision support should start top-down in the hierarchy of LCA levels, and extension of the work should continue only when and if required by the decision to be supported and the conclusions to be drawn. This point is important, as one of the most important barriers to the practical use of LCA in decision support is the volume of work needed.

4.1 Matching the basic LCA level to the decision

Starting top-down, LCA work starts by making an overview of the potential impacts of the studied object throughout its life span, e.g. in a matrix as illustrated in **Table 1**.

It is well acknowledged that a categorization of impact sources after the MECO principle leads to a grouping of source types with a minimum of overlaps between the impacts deriving from these sources (COWI, 1997; WENZEL et al., 1997). Such a matrix, therefore, provides a simple but well covering overview of potential problem types throughout the life of the studied object.

The energy input in each of the life cycle stages can quite easily be quantified, and this gives quite a good backbone of the matrix based assessment. A qualitative picture of other problem types can then be given by raising flags and giving a textual description, e.g. consumption of sparse metals, emission of hazardous substances or problems like extensive land use. Doing the matrix LCA requires a fair energy database and knowledge of the product life and the processes in it. Regarding the qualitative nature of the processes, not quantitative inputs and outputs, makes the matrix LCA less time consuming to do than a quantitative LCA.

Some conclusions of e.g. improvement potentials can be drawn already from this picture, and for some decisions, there may not be a need for further quantification or detailing of the LCA (→ *Box 1*). In other cases, however, the decisions to be taken require further quantification and detailing.

Trade-offs – need for quantifying the LCA

If the decision implies essential trade-offs, e.g. between energy consumption and emission of hazardous substances from chemicals, a need for further quantification is born. This can be the situation when e.g. a reduction in hazardous substance emission can be achieved at the expense of extra energy consumption or *vice versa*.

Essentially, such trade-off situations are the reason for quantitative impact assessments in LCAs, including final weighting between impact categories. In case the decision implies such essential trade-offs, where the advantages and disadvantages are not instantly clear, a need for a quantitative impact assessment arises, and it is necessary to proceed at least to the level of a quantitative screening LCA.

Data availability – need for detailing the LCA

A screening LCA is established on the basis of readily available data. If the decision implies changes in systems/processes, that are judged to be significant but not covered by the readily available data, a need for further detailing and new data collection is born.

4.2 Modelling the actual environmental consequence of the decision

The actual environmental consequences of a decision derive from the changes in input and outputs from the industrial system that are caused by the decision. The modelling of these changes is the cornerstone in any LCA, and the match of the model to the actual consequence of the decision is, of course, crucial to the suitability of the LCA to support the decision.

Table 1: A matrix LCA

Type of impact	Materials	Manufacture	Use	Disposal	Transport
Materials (e.g. resource consumption and waste related problems)	*			*	
Energy (e.g. fossil fuel consumption, global warming, acidification, nutrient enrichment)	x_1 MJ	x_2 MJ	x_3 MJ	x_4 MJ	x_5 MJ
Chemicals (e.g. toxicity, ecotoxicity, ozone depletion, oxidant formation)		*			
Other (e.g. biodiversity depletion, landuse, non-chemical working env. problems)	*	*			

* = "raising of flag" – a qualitative problem description

A consequence of this is, that data for the various processes of the modelled systems should always represent the so-called marginal technology for the process, because the marginal technology is per definition the one that is changed due to the decision in question. The issue of using data for marginal technology is elaborated in more detail in e.g. FRISCHKNECHT (1997) and WEIDEMA and FREES (1998).

When doing this modelling in the application of LCA to different decisions, it becomes clear that especially two variables differ from application to application. These variables are time and space.

4.3 Time scale – need for trend analysis and projection

In some applications, the LCA supports decisions that affect industrial systems many years ahead, e.g. LCA used in product development. For such applications, the systems affected must be projected in order to reflect the future in the best possible way. In other applications, the LCA supports decisions that affect present industrial systems only or only reach a few years into the future, e.g. LCA used in product marketing. In such applications, a description of the present status of systems is needed.

Note, that it is the time scale of the decision, which is relevant. One consequence of this is, that there is no such thing as a historical LCA, even for environmental declarations of products produced a while ago. Because if such an LCA is used to support any decision, this decision will affect activities of today or tomorrow and not activities of the past.

The issue of the time scale largely influences the scoping and inventory components of the LCA method. It gives rise to a need of a trend analysis and a projection of essential processes and key assumptions in the model of the systems in question.

4.4 Site dependency – need for site specific information

In some applications, the locations of the various processes in the product system are to a wide extent fixed and known, e.g. for LCAs used in marketing. In such applications there is a need and a possibility to include site specific/site dependent information in the LCA, because the decision will affect the specific product and processes comprised by the marketing information. In other applications, the locations of the processes are not fixed and to a wide extent unknown, e.g. for LCAs used in product development. In such applications it is more difficult to include site specific information and to some extent it is also undesirable, because data should rather reflect broad averages than site specific details.

The issue of site specific information influences the scoping, the inventory and the impact assessment components of the LCA method. It affects the identification of the marginal technologies during scoping, the data requirements during inventory and it may affect the procedure of the impact assessment. **Table 2** presents some examples of LCA applications and shows how they differ on the issues related to time and space.

The time and space issues are interrelated in the sense that the time aspect to some extent affects the availability and the need for site specific information. As shown in **Table 2**, the tendency is that the larger the time horizon of the decision, the less both the availability and the need for site dependent information. This can be illustrated as in **Figure 3**.

Table 2: Examples of LCA applications and their differentiation on issues related to time and space

Specific application	Type of decision support	Time scale, T (years)	Availability and need for site specific information
Societal action plans and legislation	Identify best societal strategy for a given problem/product group	$2 < T < 2 + P + L$	+
Product development	Form background for environmental specifications and for design strategies, principles, and rules	$2 < T < 2 + P + L$	+
Production technology assessment	Identify Best Available Technology from a life cycle perspective	$1 < T < 1 + L$	+++
Ecolabelling – criteria setting	Identify environmentally essential product properties for a product category	$1 < T < 4$	+
Supplier requirements	Choice between alternative suppliers, materials & components	$1 < T < 4$	+++
Marketing	Document potential (or actual) burdens for a specific product	$0 < T < 1$	+++

T= time scale for which decision should be valid (examples)
P= time for which product is in production
L= life time of product/process
+ = smaller, ++ = medium, +++ = larger (relative indications)

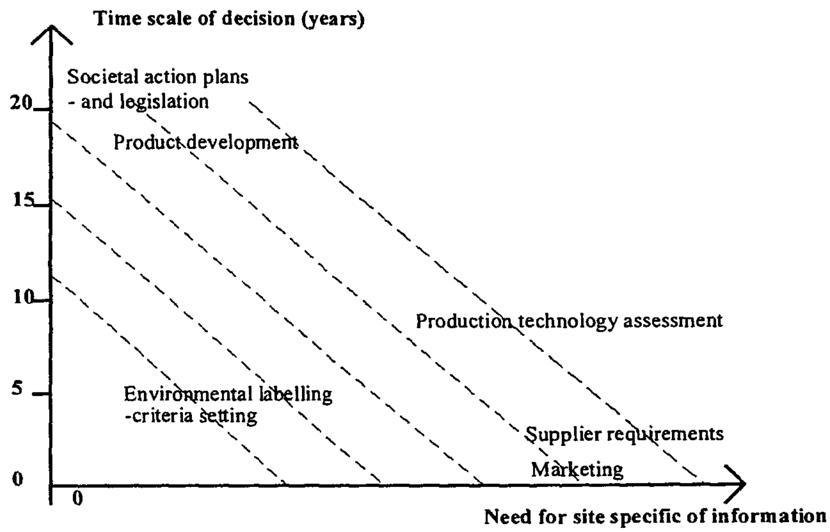

Fig. 3: Examples of LCA applications which differ in the time scale of the decision and in their need for site specific information

5 The Economic or Social Consequence of the Decision – Need for Certainty, Transparency and Documentation

Till now, the variables have been discussed that concern the modelling of the environmental consequence of the decision. The influence of these variables can be derived from mainly technical considerations of how to establish the most suitable model. On top of these technical considerations, however, lie some more social and economic considerations.

Part of the LCA has to do with cut-off criteria, certainty and uncertainty assessments, transparency and documentation. These elements of the LCA all have to do with the burden of proof within the LCA, i.e. the need to verify and justify the validity of the conclusions and the decisions taken. And the work to be put in those elements of the LCA will in practice depend much on the social and economic importance of the outcome of the study. **Figure 4** illustrates this point and gives some examples of applications with different requirements to certainty, transparency and documentation.

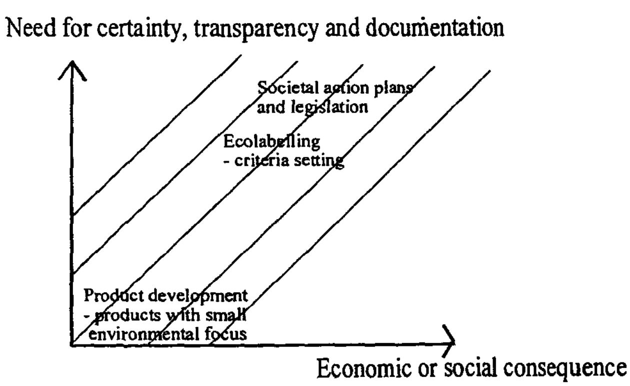

Fig. 4: Examples of LCA applications with different need for certainty, transparency and documentation caused by difference in economic or social consequence of the decision to be supported

It must be pointed out, that the various application areas cannot easily be plotted in the above figure, because within each application area may be found decisions with both very large and only small economic or social consequences. Within product development for example, some products are under a very large environmental focus in society, e.g. packaging products, while for others, e.g. a screw driver, environmental focus is almost non-existing. For some product categories, guidelines for green public purchase exist, and an LCA for environmental declarations for such products will be given very high attention as to certainty and documentation, if public institutions are important customers.

Therefore, the considerations must be case specific. If there are absolutely no trade-offs related to the decision and all essential data are readily available, a matrix LCA can be enough even if there is large economic or social consequences related to the decision. This could be the case for the example given in Box 1, which illustrates a matrix LCA used in product development of a simple valve and some potential decisions to be supported by this LCA. In other cases, a full LCA must be done, even though the economic and social consequences are small, if the decision is of a nature, that requires answers to trade-offs and collection of new data. The economic and social consequence has therefore nothing to do with the depth of the LCA according to the previously describes levels of LCA, but merely with the requirements for the documentation of the validity of the conclusions behind the decision.

Box 1: Matrix LCA for decisions in product development of a mechanical valve for a central heating plant

Application area:	Product development, improvement strategies
Materials and lifetime:	Material: Brass Weight: approx. 500 g Life time: approx. 40 years

Matrix LCA:

	Material	Manufacture	Use	Disposal	Transport
Materials	Cu cons. Zn cons.			Cu+Zn loss Cu in steel	
Energy (MJ)	35	18	Friction: 65 Heatloss: 800	Steel contamination: 950*	2
Chemicals		Greasing and degreasing agents			
Others					

* A percentage of the valves will follow the steel of the central heating system to steel recovery (the matrix LCA anticipates 50%). Cu contaminates steel and gives rise to the need of addition of primary steel to keep the Cu-concentration down. The energy consumption in disposal reflects the energy content in this primary steel.

Improvement options and potential trade-offs and data gaps:

Option 1: Design in plast

Oil (in the plast) is less sparse than Cu and Zn, and savings of fossil fuel for disposal will be much greater than the oil used for the plast. Furthermore, the plast valve will contribute to the heating of the steel during melting, and its heat value will thus be regained during disposal. Injection moulding of plast can often be done without greasing and degreasing, and less hazardous chemicals are used for injection moulding compared to the shaping in brass. There are, thus, no trade-offs between neither resource consumption and energy nor chemicals and energy. The decision to design in plast instead of brass, therefore, needs no further quantification or detailing of the LCA.

Option 2: Co-design valve and insulation, increase insulation

The insulation material can be doubled many times before the energy content of the insulation outweighs the energy reduction during use. No trade-offs between resource consumption and energy exist. There may be impact types related to production of insulation material, that are not related to the energy production, e.g. impacts in working environment (Others). There could be a need to look into these trade-offs, however intuitively they seem to be in favour of the increased insulation.

Option 3: Reduce friction

A reduction of friction was judged possible, and will probably not involve extra material consumption. Designing the valve as an on-off valve will prohibit the user to forget to open the valve completely (thereby increasing friction) after use of the valve. This will neither increase material consumption. The decision to design the valve as an on-off valve, thus, implies no trade-offs.

6 The Decision Context – Implicit Assessment and Weighting Criteria

It has been widely criticized that LCAs can be twisted to yield the conclusions desired by the sponsor of the LCA. That subjective assumptions, cut-offs and values can be mingled to yield a desired result. To a large extent, method development and standardisation have aimed at avoiding this situation by development of scientifically sound and standardised procedures.

Despite all standardisation effort and success, however, it must be faced, that the questions asked, i.e. the decision to be supported, implicitly do and should influence the method.

A simple example of this could be that a company wants to clarify, whether important trade-offs exist between environmental impacts and impacts in working environment when introducing a new product or technology. Such a study must, of course, include working environment as an impact category, and the decision in question thus implicitly influences choice of assessment criteria.

Another example could be, that an environmental authority wants to reduce environmental impacts from beverage packaging systems. In the weighting of different impact categories against each other, the authority may want to use the reduction targets for each impact category (in a distance-to-target weighting) that can be derived from existing environmental policies and improvement measures in society. In that way, the authority would ensure that the product oriented measure and other measures across sectors in society pull in the same direction. LCA can be seen as a management tool to ensure this, and this principle of weighting therefore becomes a natural part of the task to be solved. Another stakeholder might then want to see how priorities would look, if an expert panel weighting was used instead, and in that case the weighting component would again be given by the decision context.

Other parties affected by the decision in question may as well have implicit interests in the scoping and impact assessment components. Neighbours to a given plant might have an interest that noise is included as assessment criterion and may speak for a site specific approach in a given decision, and so on.

Such contextual requirements for the method within a given decision support call for a thorough investigation of interested parties. They will typically exert their influence on the method in the definition of assessment criteria and on the impact assessment including considerations for site dependency and values in the weighting.

7 Overview of the Key Variables' Mode of Influencing the LCA Method

The identified variables exert their influence on each their part of the method as previously described. An overview of their mode of influence is gathered in **Table 3**.

8 Conclusion

The need to differentiate the LCA methodology when used in different applications derives from a limited number of variables. These variables all derive from differences in the consequence and the context of the decision to be taken.

The essential variables are:

1) the environmental consequence of the decision, including

– the extent of the consequence in time and space, primarily causing differentiation in requirements for scoping and inventory

Table 3: Elements of the method affected by the key variables and the influence exerted

	Environmental consequence of decision				Large socio-economic consequence	Decision context
	Trade-offs	Data gaps	Large time scale	Site specificity		
Scoping						
Assessment criteria						May imply inclusion of certain assessment criteria
System model - technology level			Implies a need for trend analysis and data projection	Implies a need for site specific data		
- allocation model			Increases difficulty in system extention	Increases the need for site specific system extention		
- cut-off criteria					Increases the need to be certain that all essential is included	
Inventory						
Data collection		Implies a need for new data inventory	Implies a need for data projection	Implies a need for site specific data		
Aggregation model				May imply a need for site dependent ajustment prior to aggregation		
Impact assessment						
Impact potentials	Implies a need for quantitative impact assessment			May imply a need for site dependent ajustment		
Normalization				May imply a need for region dependent normalization		May imply use of certain normalization references
Weighting				May imply a need for region dependent weighting		May imply use of certain weighting criteria
Uncertainty and sensitivity analysis						
					Increases the need for uncertainty and sensitivity analysis	
Documentation						
					Increases the need for transparency and data documentation	

- the existence of trade-offs between impact categories, primarily causing differentiation in requirements for impact assessment

2) the economic or social consequence of the decision in question, primarily causing differentiation in requirements for certainty, transparency and documentation

3) the context of the decision, especially the elements that implicitly derive from the problem to be studied or the task to be solved in connection with the decision; primarily relates to impact assessment.

Knowing these variables and their way of influencing the methodology facilitates the identification of the specific needs within a given LCA application.

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Conference Reports: First LCA Workshop in Greece

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On December 16th, 1997, the first Greek workshop on LCA was organised at the Aristotles University of Thessaloniki by the Laboratory of Heat Transfer and Environmental Engineering (LHTEE). The meeting was held in the city of Thessaloniki with many attendees from industry and academia.

The aim of the workshop was to present the new environmental tool of LCA to the Greek community in general, to exchange ideas and to have an initial impression of the areas in which LCA could be applied in Greece. The papers presented at the workshop covered the whole spectrum of the industrial activity in the country.

The presentations were arranged in such a way as to first introduce the participants to this new tool and then have a series of applications which revealed the need to reinforce LCA in all phases of production. The methodology of LCA was presented combined with the history of its usage in different phases of production and in different countries. The connection of LCA with the ISO 14000 series was demonstrated and the requirements how to implement this certificate. The application of LCA in the Greek telecommunication industry was shown, in a company that has already obtained the ISO 14001 certificate. Since Greece has a big food industry, LCA could play a major role in reducing the energy consumption and the waste that frequently ends up in the Greek rivers; the environmental treatment industry is not very well developed. Even though Greece does not have a big chemical industry, it is the biggest environmental polluter that concerns everyone.

A paper was presented on the application of LCA in the chemical industry; another participant analysed the area of energy production and the importance of LCA in selecting the form of energy as to how establish its environmental impact in comparison with its monetary value.

HELCANET, a Greek LCA network, was created for the purpose of bringing together organisations and individuals in industry and academia. HELCANET, for the present time, tries to initiate new projects (*see p. 272*).

The proceedings including all workshop presentations were published by LHTEE in Greek (Director Prof. N. MOUSSIOPOULOS and Miss A. BOURA).

For further information about the workshop, HELCANET and the registration procedure in order to become a member of the network, please refer to the following web page: http://aix.meng.auth.gr/lhtee/helcanet

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